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ENERGY TRANSFORMATION IN THE ATMOSPHERE OF THE NORTHERN AND SOUTHERN HEMISPHERES AND INTERACTION OF PROCESSES IN BOTH HEMISPHERES

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ENERGY TRANSFORMATION IN THE ATMOSPHERE OF THE NORTHERN AND SOUTHERN HEMISPHERES AND INTERACTION OF PROCESSES IN BOTH HEMISPHERES

Ye. P. Borisenkov

ABSTRACT

Seasonal variability of potential and kinetic energy in the atmosphere of the Northern and Southern Hemispheres at different latitudes is considered. It is shown that seasonal transformations of energy in both hemispheres substantially differ due to the nature of underlying surface. The necessity of the interaction of processes in both hemispheres is based on the study of kinetic energy of the zonal atmospheric motion. It was concluded that the atmospheric processes in the Northern and Southern Hemispheres are a single mechanism of circulation and cannot be studied separately.

During the International Geophysical Year (IGY) scientists in several countries seriously studied the processes occurring not only in the Northern Hemisphere, but also in the Southern Hemisphere. The result of this effort was the publication of thorough studies characterizing the thermodynamic and synoptic conditions in the Southern Hemisphere. From this group of studies, we shall single out the works (Ref. 1-5). /5*

The necessity then appeared of uniting the efforts of the scientists, in order to clarify the nature of interaction processes in the atmosphere throughout the entire earth, including both hemispheres. A new phase of development was commenced for the point of view which has been formulated in many studies, and according to which a long-range forecast must be based on patterns for general atmospheric circulation. It is now inadmissible and inadequate to study patterns of general circulation without taking the Southern Hemisphere into account. This problem interested us, not only because we were interested in clarifying the nature of energy transformation in the atmosphere of the Northern and Southern Hemispheres, but also because the processes in the Southern Hemisphere must be taken into account in numerical schemes for long-range weather forecasting.

At the present time there is still no rigorous mathematical theory

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* Note: Numbers in the margin indicate pagination in the original foreign text.

for general atmospheric circulation. Nevertheless, studies based on the theory of macroturbulent mixing (Ref. 6-9) and on the theorum regarding conservation of the absolute angular moment of the earth-atmosphere system (Ref. 10) have pointed out methods of approach to be followed in solving this problem, on the basis of quantitative considerations. This has also been indicated by studies based on determining the components in the equation of energy balance (Ref. 11-14). In several cases, these methods have been employed in different combinations. Our purpose is to examine certain energy aspects of this problem and, on the basis of this examination, to formulate ideas (which are unfortunately still qualitative) regarding the interaction processes in both hemispheres. We shall first briefly touch upon the seasonal features of energy transformation in the atmosphere of the Southern and Northern Hemispheres[1].

Three types of energy for the cold (January, 1958) and warm (July, 1958) half of the year in the Northern and Southern Hemisphere were computed for this study. Since, in accordance with the Dines theorum, the potential (II) and the internal (J) energy of the entire atmosphere are connected by the well known relationship:

$$J = \frac{1}{\chi - 1} \Pi, \qquad (1)$$

where X = Cp/Cv is the polytrope index, it is finally possible to combine the concept of potential and internal energy and to examine potential and kinetic energy. /6

The potential energy was calculated by employing the mean maps of baric topography (including AT-100), which were constructed by Kh. P. Pogosyan (Ref. 15, 3). It was assumed that the temperature was constant above 100 mb. With these facts taken into consideration, the standard working formula has the following form:

$$\Pi = a \int_{100}^{p_0} z \cdot dp + a \cdot 100 \left(z_{100} + \frac{RT_{100}}{g} \right), \qquad (2)$$

where a is the factor depending on the assumed measurement units; z_{100} and T_{100} - altitude and temperature of a 100 mb surface; p - pressure (p_0 - pressure at sea level); R - gas constant; g - acceleration of gravity.

In order to calculate the kinetic energy, we employed isotach maps constructed by Kh. P. Pogosyan for areas of 500 mb and above, including 15 mb (Ref. 16). A linear interpolation between the wind at sea level and a 500 mb level was performed below 500 mb. In the Southern Hemisphere, the kinetic energy was calculated on the basis of the mean-monthly maps of baric topography compiled by Kh. P. Pogosyan, employing geostrophic

[1] We investigated this problem in greater detail in the study (Ref. 12).

relationships. Therefore, the calculations were performed in the 20-90° N zone, and it was assumed that the kinetic energy was the same in the 0-20° N zone as it was in the Northern Hemisphere. The calculations were made on the basis of the following formula

$$K = \int_0^z \frac{v^2}{2}\,\rho \cdot dz = \frac{1}{2g}\int_0^p v^2 \cdot dp, \qquad (3)$$

where K is kinetic energy; v - wind velocity; ρ - density; z - altitude corresponding to the 15 mb level and representing the upper boundary of the layer under consideration. The integrals in formulas (2) and (3) were determined by numerical methods. In each hemisphere, all of the calculations were made for the centers of regions having the dimensions of 10° latitude and 10° longitude. In this way, there were 324 points in all in each hemisphere.

TABLE 1

ENERGY BUDGET OF THE MIDDLE ATMOSPHERE IN THE NORTHERN AND SOUTHERN HEMISPHERES DURING DIFFERENT SEASONS (IN THE CGS SYSTEM)*

Components of Energy Budget	Northern Hemisphere			Southern Hemisphere		
	Winter	Summer	Winter Minus Summer	Winter	Summer	Winter Minus Summer
J	$430{,}4\cdot10^{28}$	$447{,}7\cdot10^{28}$	$-17{,}3\cdot10^{28}$	$429\cdot10^{28}$	$437{,}0\cdot10^{28}$	$-7{,}7\cdot10^{28}$
Π	$176{,}9\cdot10^{28}$	$183{,}3\cdot10^{28}$	$-6{,}4\cdot10^{28}$	$175{,}9\cdot10^{28}$	$179{,}2\cdot10^{28}$	$-3{,}3\cdot10^{28}$
$J+\Pi$	$607{,}3\cdot10^{28}$	$631{,}0\cdot10^{28}$	$-23{,}7\cdot10^{28}$	$606{,}2\cdot10^{28}$	$616{,}2\cdot10^{28}$	$-10{,}0\cdot10^{28}$
K	$405{,}63\cdot10^{25}$	$191{,}8\cdot10^{25}$	$213{,}8\cdot10^{25}$	$698{,}2\cdot10^{25}$	$393{,}1\cdot10^{25}$	$305{,}9\cdot10^{25}$
$\Delta K/\Delta(J+\Pi)$	—	—	0,009	—	—	0,028
Mass M	$265\cdot10^{19}$	$264\cdot10^{19}$	$1\cdot10^{19}$	$264{,}5\cdot10^{19}$	$263{,}6\cdot10^{19}$	$0{,}9\cdot10^{19}$
$J+\Pi/M$	$225\cdot10^{7}$	$238\cdot10^{7}$	$-13\cdot10^{7}$	$228\cdot10^{7}$	$233\cdot10^{7}$	$-5\cdot10^{7}$
K/M	$1{,}53\cdot10^{6}$	$0{,}73\cdot10^{6}$	$0{,}8\cdot10^{6}$	$2{,}64\cdot10^{6}$	$1{,}48\cdot10^{6}$	$1{,}16\cdot10^{6}$

* J. Spar (Ref. 13) performed similar calculations for the Northern Hemisphere, utilizing only single mean maps of baric topography, including the 300 mb level.

Table 1 presents the energy budget for the middle atmosphere in both hemispheres. If the potential (internal) energy reserves for the atmosphere in both hemispheres are compared in accordance with Table 1, it /7 will be found that the Northern Hemisphere has larger energy reserves than the Southern Hemisphere during the seasons being compared - i.e., the atmosphere of the Southern Hemisphere is colder, and its center of gravity is lower, during the seasons being compared.

The kinetic energy sharply increases from summer to winter in each hemisphere. However, the overall level of kinetic energy for the Southern Hemisphere mean motion is considerably higher than for the Northern Hemisphere. Thus, the kinetic energy reaches a maximum of $405.6 \cdot 10^{25}$ erg for the Northern Hemisphere in winter. During the same period in the Southern Hemisphere, a kinetic energy minimum is observed, although this minimum amounts to $393.1 \cdot 10^{25}$ erg and almost corresponds to the kinetic energy maximum in the Northern Hemisphere. The kinetic energy difference for both hemispheres is quite pronounced during the period which represents summer for the Northern Hemisphere.

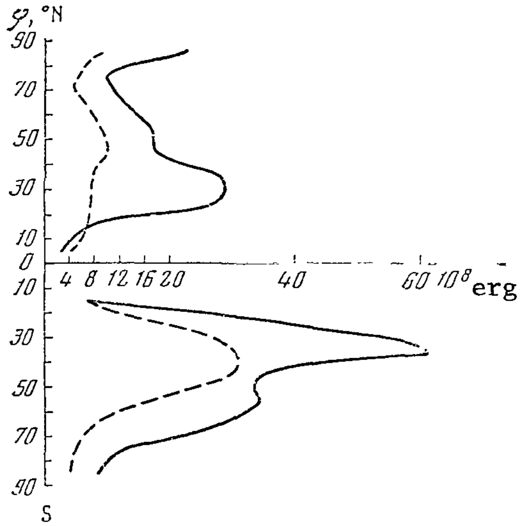

Figure 1

Latitudinal Distribution of Mean Motion Kinetic Energy in Different Seasons (in the CGS System Based on an Atmospheric Column of Unit Cross Section) Solid Curve - Winter; Dashed Curve - Summer.

In the Northern Hemisphere the kinetic energy reserves amount to $191.8 \cdot 10^{25}$ erg, while in the Southern Hemisphere they amount to $698.2 \cdot 10^{25}$ erg during the same period. In summer, the kinetic energy minimum of the Northern Hemisphere is approximately 3.5 times smaller than the kinetic energy maximum of the Southern Hemisphere.

Let us turn to the latitudinal features of the kinetic energy distribution in both hemispheres. Figure 1 presents graphs characterizing the seasonal and latitudinal features of the kinetic energy distribution for an atmospheric column having unit cross section for both hemispheres. It can be seen from this drawing that the jet stream is very clearly delineated in the Northern Hemisphere at a latitude of 30° N during the winter; it is less clearly defined in summer, and is shifted toward the north. During summer, and particularly during winter, the kinetic energy reserves are increased in the higher latitudes. This is generally observed in winter. In the Southern Hemisphere, the strength of the jet stream during summer corresponds to the strength of the winter jet stream in the Northern Hemisphere. During winter, the strength of the jet stream lasts considerably longer in the Southern Hemisphere than it does in the Northern Hemisphere during winter. /8

Figure 2 presents the latitudinal distribution of potential energy for an atmospheric column having a 1 cm^2 cross section for both hemispheres during different seasons. It can be concluded on the basis of this drawing that the potential energy increases from winter to summer in the Northern Hemisphere, beginning at a latitude of 30° N. This increase is at a maximum at the higher latitudes. We assume that the minimal seasonal changes in the potential energy at a latitude of 65° N are related to the effect of the Gulf Stream.

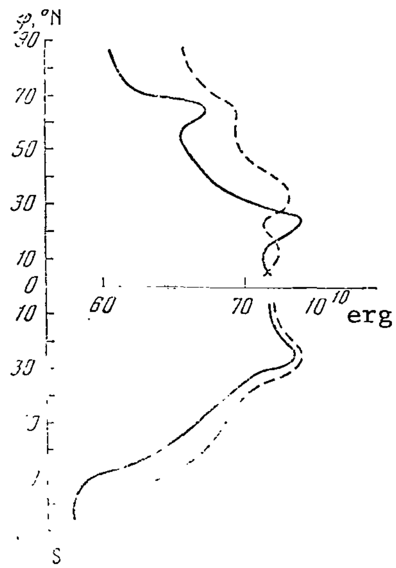

Figure 2

Latitudinal Distribution of Potential Energy in the Middle Atmosphere During Different Seasons (in the CGS System Based on an Atmospheric Column of Unit Cross Section)
Solid Curve - Winter; Dashed Curve - Summer.

The picture is somewhat different in the Southern Hemisphere. Although the seasonal changes in the potential energy sharply increase at the higher latitudes, these changes are still not large. According to data presented in Table 1, the mean seasonal changes for the potential energy in the Southern Hemisphere are twice as small as in the Northern Hemisphere. This can only be explained by the differences in the area underlying them.

Let us now turn to the following figures. If we divide the internal energy of the atmosphere in a hemisphere by the mass of the latter, we obtain a certain mean effective temperature for the atmosphere in the corresponding hemisphere. If the same procedure is followed for the potential energy, the mean altitude of the center of gravity for the atmosphere in this hemisphere is obtained. These values must correspond to the mean values for temperature and geopotential of the mean energy level. As the author has shown in several works, particularly in the works (Ref. 11), this geopotential is located close to 7,000 m.

As a result of these calculations, it can be determined that the mean effective temperature of the atmosphere in the Northern Hemisphere amounts to 232° K in winter, while the atmospheric temperature in the Southern Hemisphere is 231°.7 K in winter. In the Northern Hemisphere, the mean temperature is 242°.8 K in summer, while in the Southern Hemisphere - it is only 237° K. The altitude of the center of gravity for the atmosphere in the Northern Hemisphere is 6804 m during winter, while in the Southern Hemisphere (during the months which represent winter for this hemisphere) - 6786 m. This altitude amounts to 7070 m and 6936 m for the corresponding summer months.

In our opinion, several important conclusions can be drawn from these data.

First of all, we feel that it will be expedient in future studies to calculate the transformations of the potential and internal energy, employing the methods of the mean energy level. This facilitates the calculations to a considerable extent. It was shown in the work (Ref. 2) that the mean energy level method can be employed in calculating the stream of outgoing long-wave radiation of the earth-atmosphere system. The temperature of the mean energy level and its altitude can be calculated for these purposes on the basis of data derived from radiosonde observations according to the following formulas:

$$z_c = z_p + \frac{RT_p - gz_p}{g + R\gamma},$$

$$T_c = \frac{g}{R} z_c,$$

where z_c and T_c represent the linear altitude and temperature of the mean energy level; z_p and T_p - the altitude of the isobaric area and temperature, which are used to perform the calculation (for this purpose, it is most expedient to take the 400 or 500 mb levels); g - acceleration of gravity; R - gas constant; γ - vertical temperature gradient, wich can be set equal to 0.7°/100 m without disturbing computational accuracy.

Based on data from the artificial earth satellite "Tiros II" (Ref. 17), we compared the outgoing radiation in the 7-30 micron band with the radiation of an absolutely black body at the temperature of the mean energy level, calculated according to a formula presented in the work (Ref. 12). /9

According to data derived from 50 radiosonde observations in the United States, the correlation coefficient was 0.74 when these data were compared in time. Consequently, the mean energy level method may find application in satellite meteorology.

The second conclusion, which may be derived from analyzing the data presented above, is as follows. The opinion is held that the colder temperature in the Southern Hemisphere during winter is caused by radiation processes related not only to the difference in the underlying area, but also related to the fact that the earth is farther from the sun in this period (Ref. 18). But in this case, summer in the Southern Hemisphere would have to be warmer than summer in the Northern Hemisphere. In actuality, the mean effective temperature in the Southern Hemisphere is lower than in the Northern Hemisphere; during summer it is 5.8° C lower, while in winter it is only 0.3° C lower. Thus, an explanation for this difference must be sought not in astronomical factors, but in the difference comprising the underlying area. If we consider winter in the Northern Hemisphere, during this period the effective temperature of the Northern Hemisphere is 11.3° C higher than the effective temperature in the Southern Hemisphere.

If we assume that there is heat exchange between the hemispheres, it would have to be largest during the period which represents summer for the Northern Hemisphere. As corroboration of this, we would like to point to data givenby T. G. Berlyand (Ref. 19), an interpretation of which can be found in the work (Ref. 16). In accordance with these data, the advective temperature changes in the Northern Hemisphere reach a maximum at the lower latitudes during the summer.

Let us briefly touch upon the interconnection between the circulation mechanisms in both hemispheres. It was indicated above that the kinetic energy is approximately the same in both hemispheres in January. In July, this difference is quite pronounced. There is no doubt that the kinetic energy or zonal motion in the Northern Hemisphere must be smaller during summer than it is during winter in the Southern Hemisphere. For this purpose, the kinetic energy or zonal motion was calculated according to the mean baric topographic maps compiled by Kh. P. Pogosyan. Due to the fact that we employed geostrophic relationships, calculations were not performed for the lower latitudes. All of the calculations were performed on the ETsVM "Ural-2" (computer); the results of these calculations are shown in Figure 3.

It can be readily seen from Figure 3 that the kinetic energy for the zonal stream of the Northern Hemisphere is 2 $^1/_2$ times smaller during summer than it is in the Southern Hemisphere during the same period.

In recent years, the theorem regarding the retention of the absolute angular moment of the earth-atmosphere system has again begun to occupy a significant position in research on general circulation of the atmosphere. Up to the present, its application has generally been restricted

Figure 3

Kinetic Energy Distribution of Mean Zonal Motion for the Northern Hemisphere During the Warm Portion of the Year (In 10^5 erg Based on an Atmospheric Column Having Unit Cross Section) to one hemisphere. Based on this theorem, attempts have been made to explain the intralatitudinal macroturbulent exchange in the Northern Hemisphere. However, the data presented above justify the assumption /11 that during the summer the stream having angular moment from the atmosphere to the earth is not balanced in the moderate zones located in both hemispheres. This balance can only result from the macroturbulence exchange between hemispheres. There are indirect data which substantiate this line of reasoning.

TABLE 2

MEAN NUMBER OF DAYS WITH MAIN FORMS OF CIRCULATION (1890-1950)

Forms of Circulation	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Eastern (E)..	12	11	12	11	11	7	8	9	8	10	11	13
Meridian (C).	7	7	8	9	11	11	11	7	7	7	6	6
Zonal (W)....	12	10	11	10	9	12	12	15	15	14	13	12

Table 2 presents the mean number of days with different forms of circulation (according to G. Ya. Vangengeym) (Ref. 20). A graph was constructed on the basis of this table (Figure 4). This graph shows the annual variation in the number of days having a zonal form of circulation (W) and the number of days having a variety of meridian types of circulation (E + C). In accordance with these data, the meridian maximum falls in May in the Northern Hemisphere[1]. If the fact is taken into consideration that late autumn is observed in the Southern Hemisphere in May - and the autumn processes, as is known, are not less intense than the winter processes - one then has the impression that the meridian effect in the Northern Hemisphere is related to the processes in the Southern Hemisphere[2].

We shall not deal with the mechanism for this interaction here. A great deal of new research is required to clarify this; however, several considerations can be advanced. In the first place, we feel that important conclusions regarding the interaction mechanism can be reached only on the

[1] According to the recent data of A. A. Girs (Ref. 21, 22), obtained from more extensive material, the meridian maximum falls in May-July.

[2] We should point out that the occurrence of a meridian maximum during a warm period has not been clarified up to the present. However, it has been found that this fact cannot be explained by atmospheric circulation patterns only in the Northern Hemisphere.

basis of the macroturbulence theory. It is primarily necessary to clarify the nature of the observed extreme of kinetic energy at the latitude of 30° N, which is directed toward the north (Ref. 11). Its maximum is not related to the mean meridian circulation, but to the large-scale eddys. Up to the present it has been assumed that one of the most important sources of this energy is the heat of condensation in the tropical regions. The possibility is not excluded that the stream is determined by a more complex mechanism of interaction between the circulation processes in both hemispheres - the necessity of which was justified above - and its source must be sought not only in the tropical zone.

The second fact to which we would like to call attention is as follows. Based on the statements given above, it is possible to explain the fixed relationships between the increase in solar activity and the disturbances of zonal circulation, and to explain a certain shift between them in time. Since it has been shown that the difference in the atmospheric energy balance in the hemispheres can be explained by the difference in the underlying area, the phenomena of solar activity are manifested in the irregular change in the atmospheric energy balance, which does not take place immediately, but only after a certain period of time. This is initially indicated in the change in the internal (potential) energy of the atmosphere, and then in the change in its kinetic energy - particularly, kinetic energy of zonal motion. In order that the angular

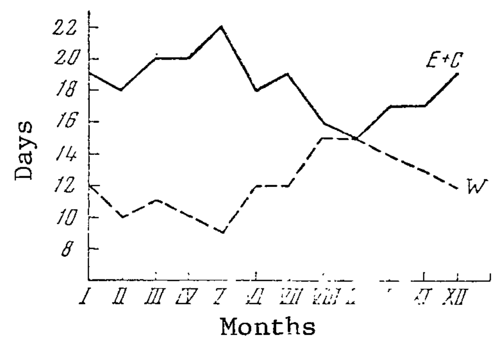

Figure 4

Mean Value for Days in a Month Having Different Types of Circulation in the Northern Hemisphere
Solid Curve - Meridian Types of Circulation (E+C);
Dashed Curve - Zonal Circulation (W).

moment of the earth-atmosphere system be equalized, the zonality is disturbed at a later time, which is manifested in a macroturbulent exchange both within the hemispheres and between them. These disturbances must apparently take place at the point where the developing instability, in the sense of energy contrasts, is the greatest. /12

In all of the above statements, we feel that it is important to draw serious attention to the energy aspects of overall atmospheric circulation. Such an approach makes it possible to employ the same units in combining the heat influxes, changes in the internal energy of the system, changes in the kinetic energy of mean motion, and changes in the kinetic energy of large-scale turbulence. After these data are assembled, it will be possible to compare the patterns which are obtained, not isolated from each other but rather on the basis of a single energy mechanism. It appears that such an approach would be very advantageous when studying the entire geophysical complex.

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